The Johns Hopkins University/Applied Physics Laboratory
Final Report
UWB-GPS Compatibility Analysis Project

The Johns Hopkins University Applied Physics Laboratory submits the following errata to their *Final Report UWB-GPS Compatibility Analysis Project,* which was filed on 09 March 2001 as a comment to ET Docket 98-153. These errata do not change the conclusions in the Executive Summary nor the measures of performance in Chapter 6. These errata correct a few errors that were discovered while briefing the contents of the report to various agencies.

The errata for Chapter 5 and Appendix A are due to publication errors. The errata for Chapter 4 and Appendix B are due to a misunderstanding with regard to the original test setup. For each text error, the following information is provided: the original text, the corrected text, and an explanation of the source. For each graphic error, similar information minus the original incorrect graphic is provided. To facilitate modification of individual copies of the report, full replacement pages are included at the end of this document.

1. **Page 4-11 (next to last paragraph)**

   UWB PADs were coupled to different RF networks for the conducted and radiated tests. In both tests, the UWB PAD output is piped through a 3-dB attenuator, then a high-pass differential type filter. The next effect is to reduce the energy in the 0-2 GHz range. In the conducted tests, the filter output is piped through another 3-dB attenuator. In the radiated test, the UWB PAD output is piped through the UWB antenna.

   Should read: “UWB PADs were connected through a high-pass filter directly to an RF network for the conducted test and directly through the same high-pass filter to an antenna for the radiated tests.”

   Explanation: During discussions with the experimental team and the PAD design engineer, there was a misunderstanding about the nature of the high-pass filter connection. The question related to if and when there were 3-dB attenuators associated with the high-pass filter. This matter has been reviewed and we now understand that the PAD was connected directly to the high-pass filter and the high-pass filter was connected directly to the conducted test network (as shown in Figure 5-1, page 5-3) and also connected directly to the antenna for the radiated tests. This misunderstanding produced other errors discussed in the remainder of this document.

2. **Page 4-13 (first paragraph)**

   UWB Signal Emitters were coupled to RF networks for the aggregate tests. A UWB Signal Emitter output was piped through a 3-dB attenuator, then a high-pass filter and then through the UWB antenna.

Should read: "In the aggregate tests, the UWB emitters were each connected directly to the same kind of UWB antenna."

Explanation: See item 1 above.

3. **Page 5-28 (Figure 5-18)**

   Replace the original Figure.

   Explanation: The 5-MHz PRF image was inadvertently repeated for the 10-MHz PRF figure when the report was generated.

4. **Pages A-23 and A-24 (Figures on both pages)**

   Replace the original Figures.

   Explanation: Illustrations using an earlier method of normalization were inadvertently used for these ASHTECH Z-12 measures of performance.

5. **Page B-6 (first two full sentences)**

   One final adjustment is required to account for the UWB source having a 6-dB lower power into the antenna than the value used in the conducted test setup. Therefore P_{UWB} in the equivalent range equation is set at –40.9 dBm (again this is the GPS bandwidth limited power).

   Remove both sentences.

   Explanation: This is another reflection of the issue noted in item 1 above. Originally the analyst doing Appendix B believed that when the UWB source was used in the radiated tests, there were two 3-dB attenuators added to the configuration (on each side of the high-pass filter). ARL:UT has now confirmed that there were no additional attenuators added for the radiated tests and the UWB source power level required no adjustment.

6. **Page B-7 (the two equations)**

   Replace the incorrect coefficients in the equations for R_L and R_{LdB}.

   The correct equations for Page B-7 are shown below:

$$R_L = \sqrt{\frac{0.38}{k_{attn}}} = 0.62\sqrt{\frac{1}{k_{attn}}} \quad meters$$

or:

$$R_{LdB} = \left(-2.1 + \frac{Attenuator\ Setting}{2}\right) \quad dB\text{ - }meters$$

   Explanation: See item 5 above.

7. **Page B-9 (the two equations)**

Replace the incorrect coefficients in the equations for R_L and R_{LdB}.

The correct equations for Page B-7 are shown below:

$$R_L = \sqrt{\frac{2.64}{k_{attn}}} = 1.62\sqrt{\frac{1}{k_{attn}}} \quad meters$$

or:

$$R_{LdB} = \left(+2.1 + \frac{Attenuator\ Setting}{2} \right) \; dB\text{-}meters$$

Explanation: See item 5 above.

8. **Page B-11 (Figure B-6)**

Replace the original Figure.

Explanation: See item 5 above.

9. **Page B-12 (Figures B-7 and B-8)**

Replace the original Figures.

Explanation: See item 5 above.

10. **Page B-14 (Figure B-11)**

Replace the original Figure.

Explanation: See item 5 above.

The following are replacement pages for the JHU/APL Final Report, UWB-GPS Compatibility Analysis Project dated 8 March 2001:

Pages:
4-11, 4-13
5-28
A-23, A-24
B-6, B-7, B-9, B-11, B-12, B-14

and no data encoding will fire a pulse once in every 100 nsec window. The time the pulse is fired is defined by the following equation:

$$tfire_n = t_0 + 100 * (n - 1) + d_{prn}$$

where

$tfire_n$ is the time pulse n is fired in nsec

t_0 is the time the first pulse is fired in nsec

n is the pulse number

d_{PRN} is the pseudorandom dither scale factor (0 to 12.5 nsec)

The pseudorandom dither scale factor is based on a fixed 1000 length pseudorandom code. Two different PADS were used; one for conducted (S/N 103) and one radiated testing (S/N 123). They are functionally equivalent.

UWB PADs were connected through a high-pass filter directly to an RF network for the conducted test and directly through the same high-pass filter to an antenna for the radiated tests.

Each configuration of the UWB is called a mode. The data collection effort used 18 unique modes, which are summarized in Table 4-7.

In the aggregate tests, the UWB emitters were each connected directly to the same kind of UWB antenna.

4.4 Data Hierarchy

Figure 4-1 depicts the entire ARL:UT receiver data files hierarchy with annotations describing the specific configurations for which each set of conducted, radiated and aggregate data files was obtained.

4.4.1 Conducted Data Hierarchy

The conducted testbenches were used repeatedly to acquire data from the GPS receivers as they were subject to 1) simulated GPS input only (baselines), 2) simulated GPS input plus White Noise of varying levels, and 3) simulated GPS input plus UWB energy of varying levels and from up to 18 operating modes. Each ranging tests was performed with the GPS simulator continually operating over the same 8-hour period while adjusting the injected source attenuation every 20 minutes. Every three acquisition tests were performed with the GPS simulator continually operating over the same 6-hour period while adjusting the injected source attenuation every 2 hours and performing an acquire lock, lose lock, reacquire lock cycle every 20 minutes.

The conducted, ranging folder hierarchies are shown in 4-2. The lowest level baseline folders contain data files for all receivers. The remaining lowest level folders contain a single receiver data file and a spectrum analyzer sweep file for the specific injected source, sky, mode (if UWB), and receiver. The conducted, acquisition folder hierarchies are shown in Figure 4-3. The lowest level folders contain a single data file for the specific injected source (UWB, White Noise, or none/baseline), sky, mode (if UWB), receiver, attenuation level and trial.

There are 486 total Conducted, Ranging, Live-Sky receiver data files; 81 files per receiver, comprised of 1 baseline file, 20 White Noise files, 20 UWB Mode 1 files, 20 UWB Mode 7 files, and 20 UWB Mode 13 files.

There are 2,667 total Conducted, Ranging, Min-Level receiver data files; 381 files per receiver, comprised of 1 baseline file, 20 White Noise files, and 20 files for each of all the 18 UWB modes.

There are 7,020 total Conducted, Acquisition, Live-Sky receiver data files; 1,170 files per receiver, comprised of 30 files for each of 3 baselines, 30 files for each of 9 White Noise attenuations, and 30 files for each of the 9 attenuations of UWB Modes 1, 7, and 13.

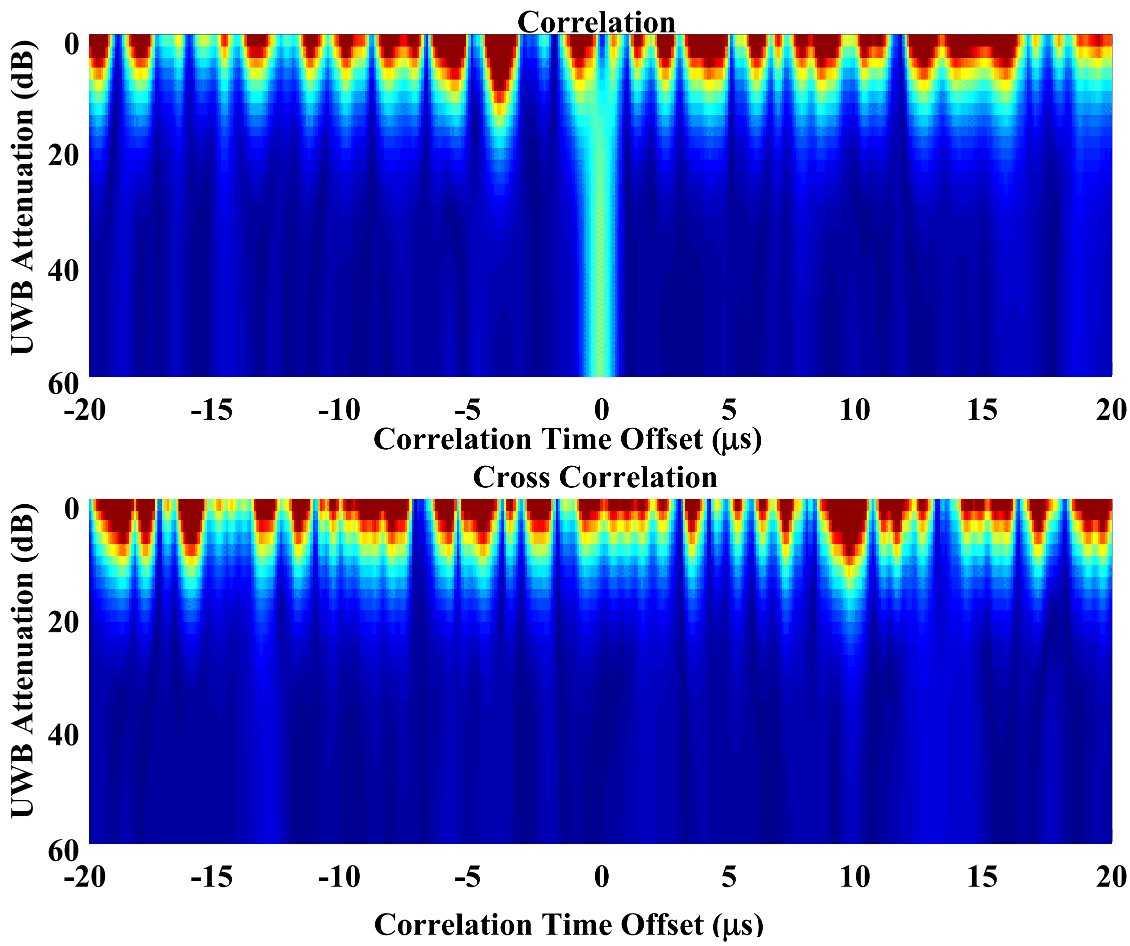
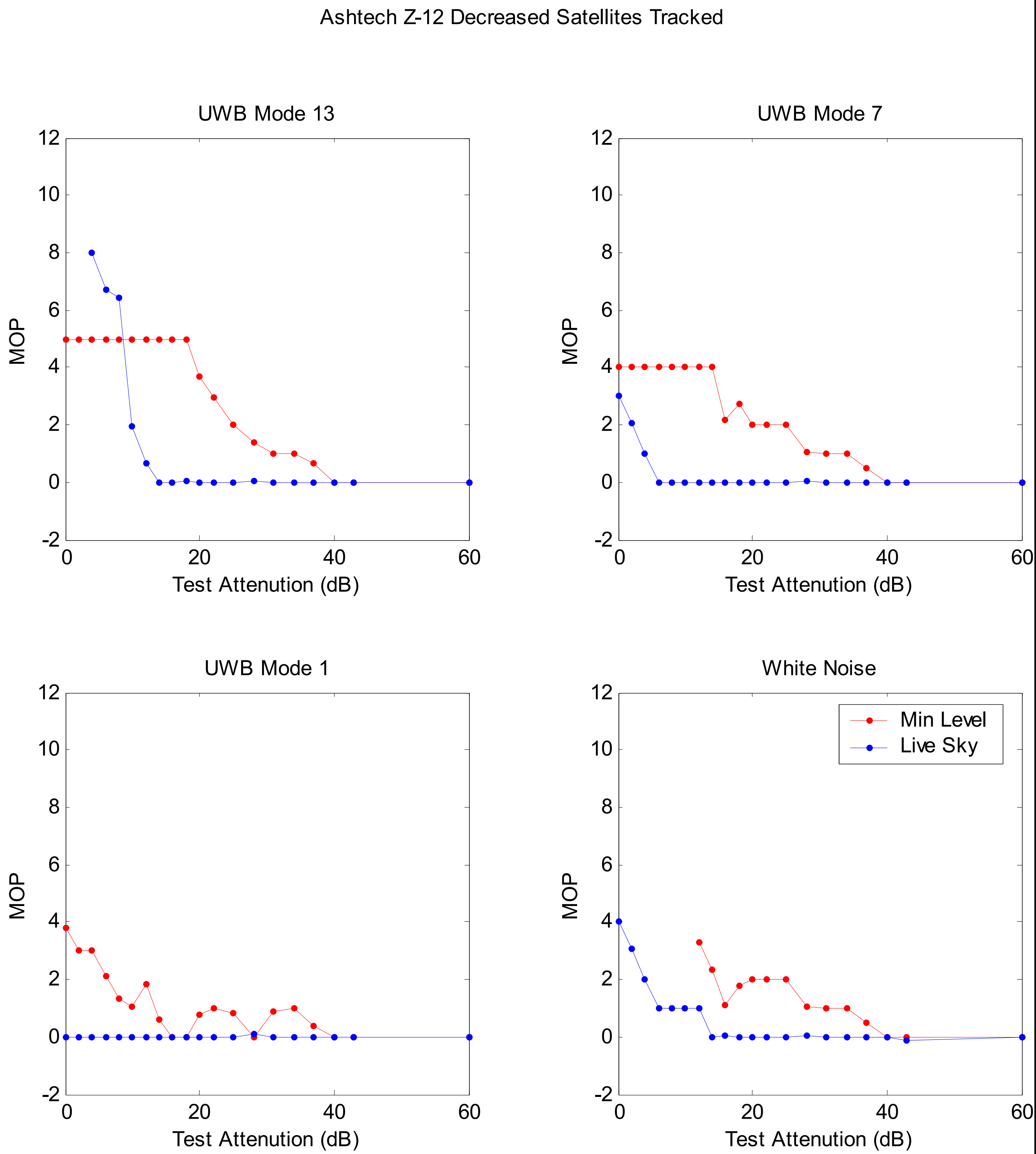
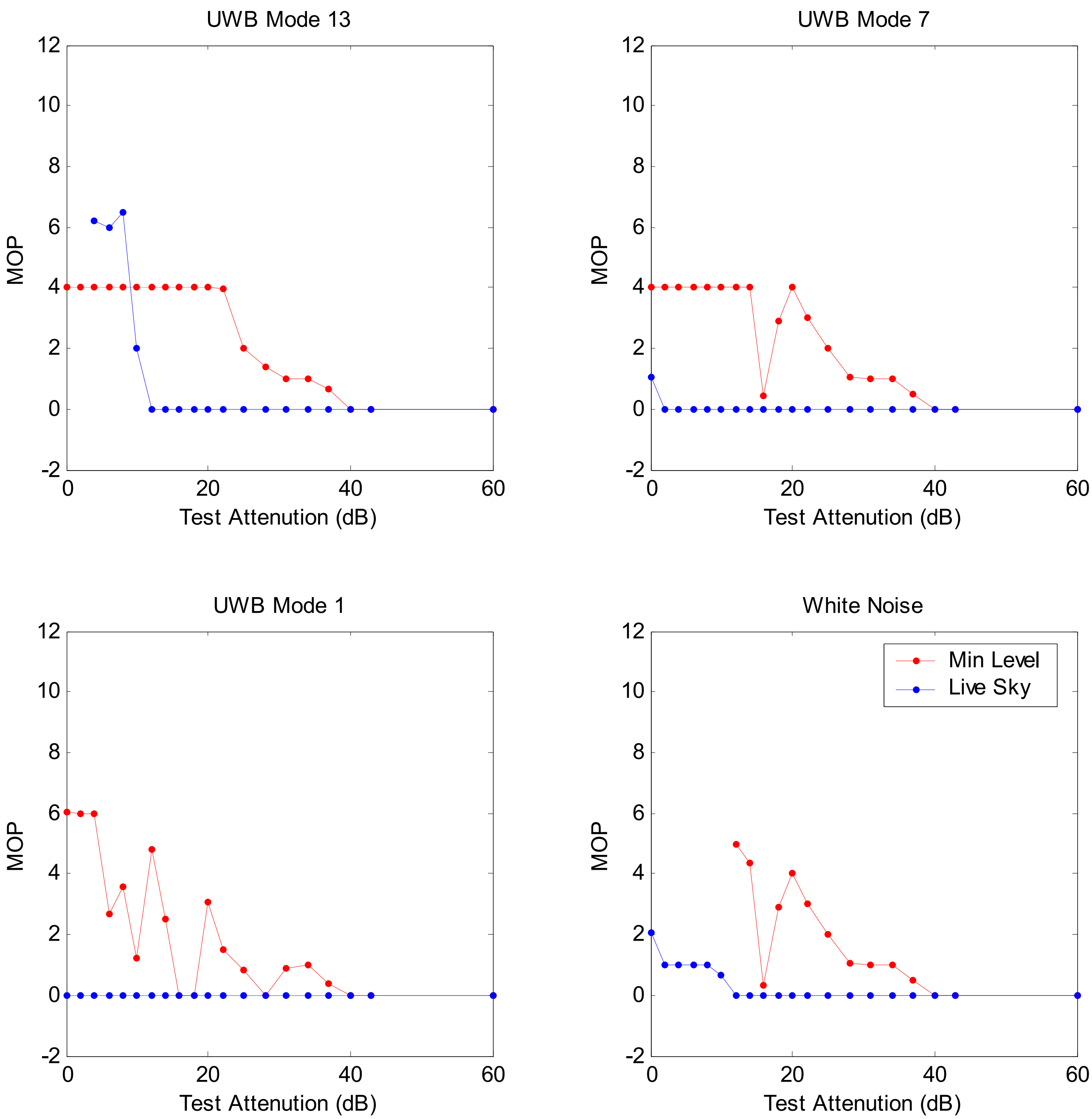


Figure 5-18 GPS Correlation with Injected UWB Signal (PRF = 10 MHz)


Ashtech Z-12 Decreased Satellites Tracked
UWB Mode 13
UWB Mode 7
UWB Mode 1
White Noise
MOP
Test Attenution (dB)
12
10
8
6
4
2
0
-2
0
20
40
60
Min Level
Live Sky

Ashtech Z-12 Decreased Satellites Used



9-dB variation in the data). Also note that the two powers, in the equation, outside the ISR represent the values for a radiated test that match the expected UWB transmit power in that test and the GPS power that would produce the C/N_0 value of the conducted test normalization. While the ISR is the value set in the conducted test.

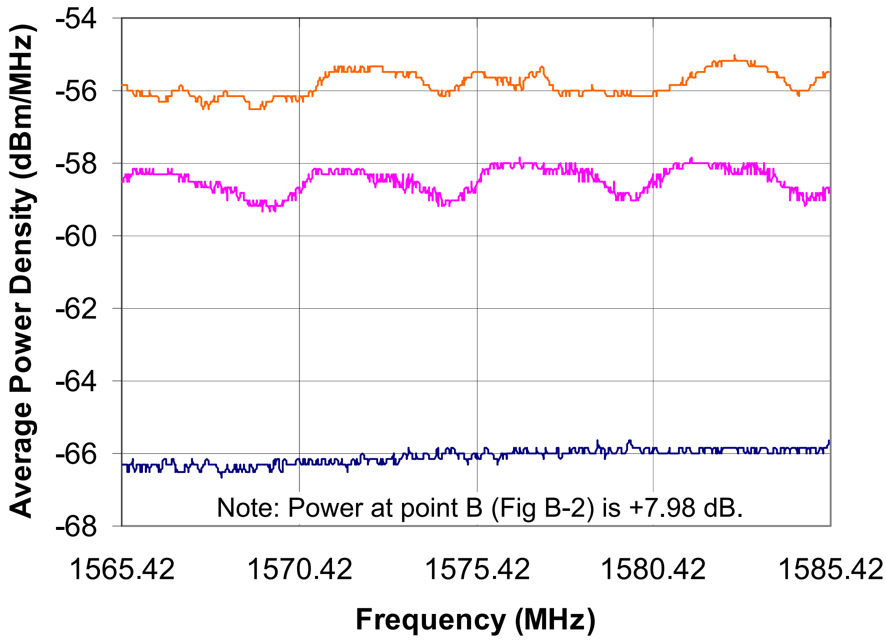


Figure B-4 UWB Average Power Densities for Modes 1, 7, and 13

As noted previously the ratio of P_{UWB}-to-$\left(\frac{P_{rUWBC}}{P_{rGPS_{iC}}}\right)$ remains constant as the mode changes, such that, the equivalent range is mode independent. This ratio for all modes is equal to –89.8 dB for the live sky condition and for the minimum level condition is –102.8 dB (includes the 6 dB radiated power reduction). When multiplied by $\left(\frac{G_t A_r}{4\pi}\right)$ and divided by the GPS power level for each condition the value in the square root is –10.2 dB for both cases. We can now restate the equivalent range equation for all conducted test conditions (for receivers 1-4) as:

$$R_L = \sqrt{\frac{0.38}{k_{attn}}} = 0.62\sqrt{\frac{1}{k_{attn}}} \quad meters$$

or:

$$R_{LdB} = \left(-2.1 + \frac{Attenuator\ Setting}{2}\right) \ dB\text{-}meters$$

Table B-2
Average UWB Power and Interference Ratio – Conducted Test Setup (Receivers 1-4)

UWB Mode	PRF (MHz)	Duty Cycle (%)	P_{UWB} (dBm)	Live-sky GPS $\left(\frac{P_{rUWB_C}}{P_{rGPS_{iC}}}\right)_0$ (dB)	Minimum GPS $\left(\frac{P_{rUWB_C}}{P_{rGPS_{iC}}}\right)_0$ (dB)
1	1	100	-45.1	38.7	51.7
2-4	1	50	-48.1	35.7	48.7
5	1	25	-51.1	32.7	45.7
6	1	66	-46.9	36.9	49.9
7	5	100	-37.5	46.3	59.3
8-10	5	50	-40.5	43.3	56.3
11	5	25	-43.5	40.3	53.3
12	5	66	-39.3	44.5	57.5
13	10	100	-34.9	49.0	62.0
14-16	10	50	-37.9	46.0	59.0
17	10	25	-40.9	43.0	56.0
18	10	66	-36.7	47.2	60.2

The above equivalent range equation is an approximation based on a simple model that makes no distinction relative to the individual performance factors of the four receivers in the setup. As noted earlier the receivers may have different noise figures and different antenna characteristics. Additionally, they are unlikely to have the same response characteristics with regard to their reported C/N_0, and since this receiver data will be used later to compute the conducted-to-radiated adjustment factor, these will also be accommodated in the final fitting process. This range equation is simply the means for estimating the initial value used in the final fitting process. However, before discussing the final fit, the initial estimate for the other conducted test setup will be defined.

The values for live-sky and minimum GPS signal levels in this setup are –87.1 dBm and –99.1 dBm, respectively. The UWB power setup was the same as it was for receivers 1-4. The equivalent C/N_0 GPS power was taken from the receiver 6 values, they were –124 dBm and –136 dBm for live-sky and minimum level respectively. The equivalent range equation for this setup is:

$$R_L = \sqrt{\frac{2.64}{k_{attn}}} = 1.62\sqrt{\frac{1}{k_{attn}}} \quad meters$$

or:

$$R_{LdB} = \left(+2.1 + \frac{Attenuator\ Setting}{2} \right) \ dB\text{ - }meters$$

Table B-4
Average UWB Power and Interference Ratio – Conducted Test Setup (Receivers 6 and 7)

UWB Mode	PRF (MHz)	Duty Cycle (%)	P_{UWB} (dBm)	Live-sky GPS $\left(\frac{P_{rUWBC}}{P_{rGPS_{iC}}}\right)_0$ (dB)	Minimum GPS $\left(\frac{P_{rUWBC}}{P_{rGPS_{iC}}}\right)_0$ (dB)
1	1	100	-45.1	35.3	47.3
2-4	1	50	-48.1	32.3	44.3
5	1	25	-51.1	29.3	41.3
6	1	66	-46.9	33.5	45.5
7	5	100	-37.5	42.9	54.9
8-10	5	50	-40.5	39.9	51.9
11	5	25	-43.5	36.9	48.9
12	5	66	-39.3	41.1	53.1
13	10	100	-34.9	45.6	57.6
14-16	10	50	-37.9	42.6	54.6
17	10	25	-40.9	39.6	51.6
18	10	66	-36.7	43.8	55.8

Although the above calculations, for both test setups, were carried out with fractional dB precision, the numbers have an uncertainty of at least several dB. The largest uncertainties are in the range of C/N_0 values experienced in the conducted baseline ranging tests. The variations in simulated signal powers for all GPS satellites appeared to be considerably smaller than the variations in C/N_0 values output by the receivers during the baseline test run (i.e., the test run without any interference). A single average value was subsequently used to define the GPS signal power condition used in calculating the conducted test equivalent range.

from the quadratic function of elevation angle for the corresponding conducted noninterference C/N_0 data points. Note that the live-sky and minimum levels for each mode are very nearly identical, demonstrating that this performance ratio is insensitive to GPS signal power (13-dB difference between live-sky and minimum level, in this test setup).

It can also be seen that the data do separate by mode. Referring back to Table B-2, the Mode 1 average UWB power is 10.2 dB less than Mode 13 and the Mode 7 is less by 2.6 dB. Figure B-7 shows the same plot with the Mode 1 data increased by 10.2 dB and with the Mode 7 data increased by 2.6 dB. This shows that the N_{I0}/N_0 ratio is directly proportional to the average UWB power level. The baseline conducted test data also provide a direct measure of the receiver-indicated C/N_0 difference between the live-sky and minimum levels without interference. This provides a direct calibration of this receiver's C/N_0 response. When this adjustment is made, it produces the results shown in Figure B-8. This correction factor was applied for each receiver. It should be noted that the higher values of N_{I0}/N_0 are only possible through the multiplication factors applied to Modes 1 and 7. The receiver would not actually produce an output with those values of interference. A value 10 to 20 times N0 are not likely, but the primary purpose of this process is to extract an equivalent range factor. Normalization to Mode 13 provides the maximum data for estimating the range factor.

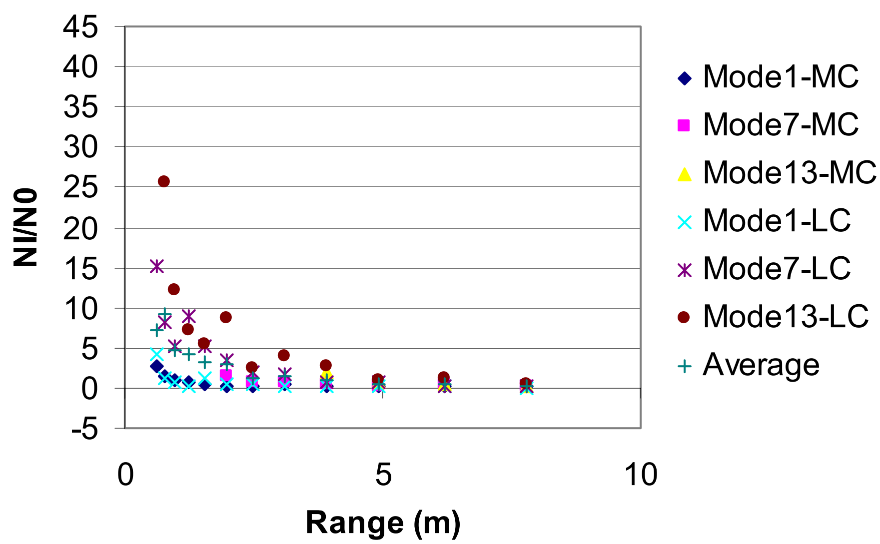


Figure B-6 Receiver 1 Conducted Test Data – Modes 1, 7, and 13 – Live Sky and Minimum Levels

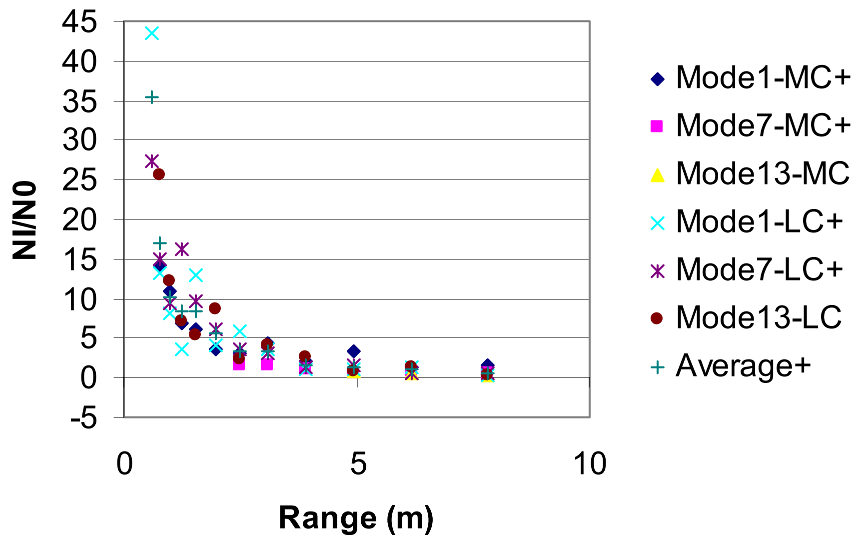


Figure B-7 Data in Figure B-6 Normalized to Mode 13 Average Power

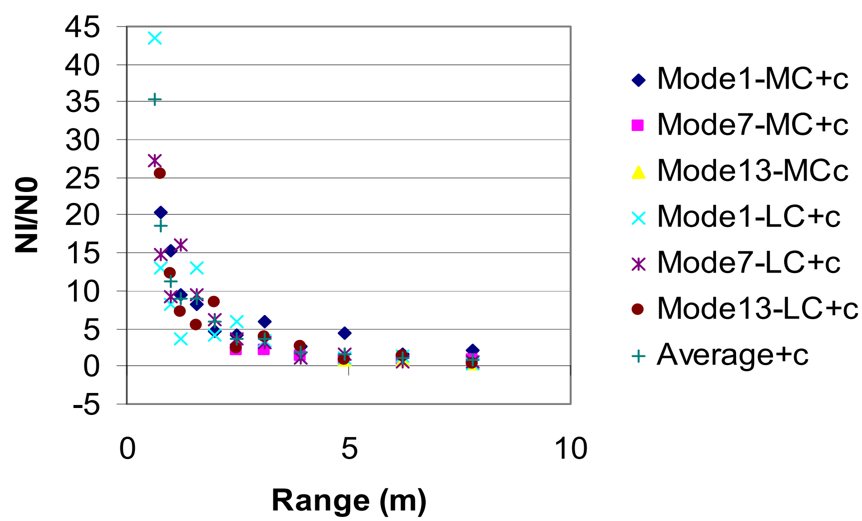


Figure B-8 Data in Figure B-7 Normalized for Receiver C/N_0 Response

The same factors (average power normalization and C/N_0 response for this receiver) apply to the radiated test data. Receiver 1 only included measurements for Mode 1 and Mode 7. The uncorrected radiated test data for the two modes and the average are shown in Figure B-9. Again the average power difference between the two modes is apparent. Figure B-10 is the same data normalized to Mode 13 power and with the C/N_0 response adjustment.

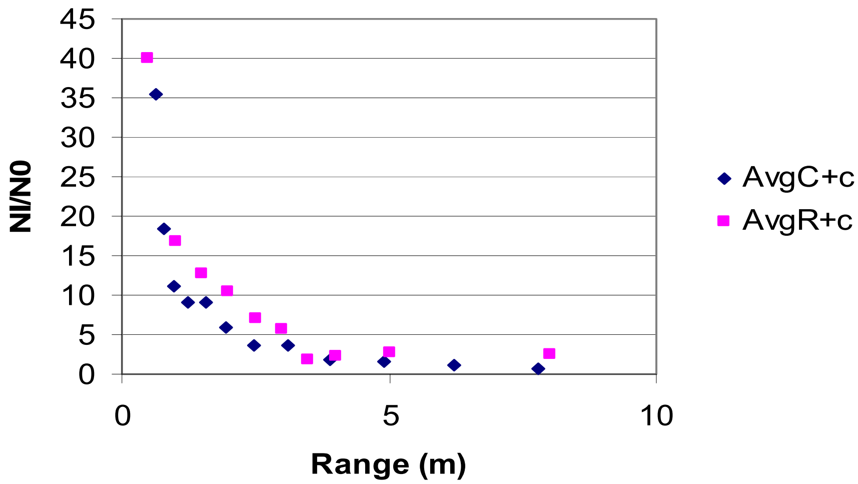


Figure B-11 Receiver 1 Conducted and Radiated N_{I0}/N_0 Measurements (Corrected)

The conducted data shown in Figure B-11 is adjusted with two factors. One factor adjusts the N_{I0}/N_0 data points to account for the difference between the power coupling and N_0 differences of the two test setups. The other factor adjusts the 0.31-meter 0-dB range value determined from the previous model calculation. The fitting process for this receiver produced the results shown in Figure B-12.

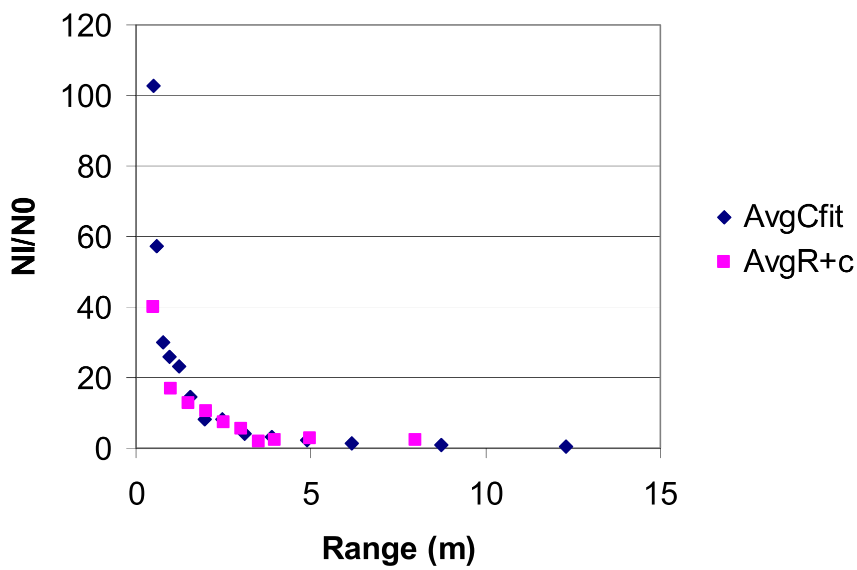


Figure B-12 Adjusted N_{I0}/N_0 Conducted Test Data for Receiver 1